MAGMAS WITHOUT BORDERS

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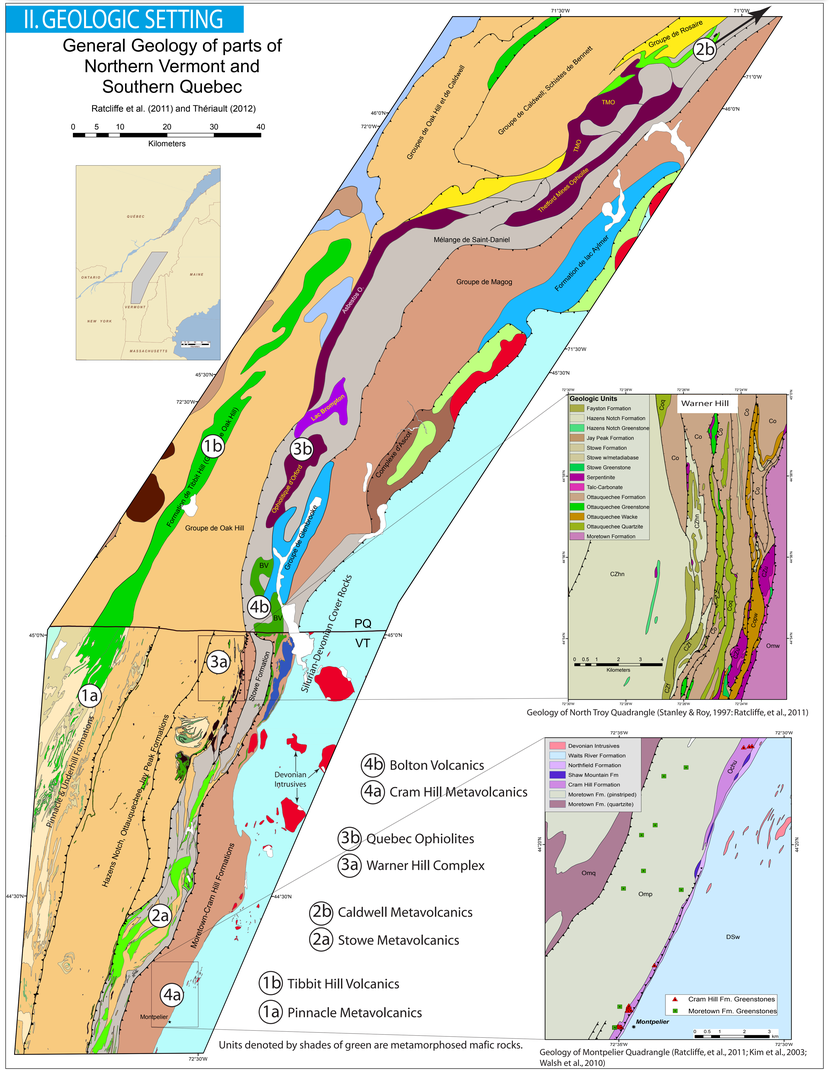
I. ABSTRACT

Metamorphosed igneous rocks in northern Vermont can be directly linked to equivalents in Québec and provide important constraints on tectonic models for the New England-Québec Appalachians. Four magmatic suites in west-central Vermont can be correlated across the international border: 1) Neoproterozoic rift volcanics A; 2) Neoproterozoic rift volcanics B; 3) Early Paleozoic suprasubduction ophiolitic rocks; 4) Early Paleozoic suprasubduction arc-backarc dikes and volcanics. Neoproterozoic rift volcanics A are represented by greenstones in the Pinnacle & Underhill Formations of Vermont and by the Tibbit Hill volcanics of Québec. They were alkali to tholeiitic basalts with high-Ti, light rare earth element-enriched compositions. Neoproterozoic rift volcanics B are represented by greenstones in the Stowe Formation of Vermont and metavolcanics in the Caldwell Formation in Québec. They have moderate Ti contents and show light rare earth element depleted or flat patterns. Both groups are interpreted as magmatism associated with the opening of the Iapetus Ocean. Cambrian-Ordovician suprasubduction ophiolitic rocks are preserved in Vermont as partially serpentinized ultramafic bodies (e.g., East Dover, Ludlow) and as meta-volcanics and dikes in the Warner Hill Complex of northern Vermont. High Cr/Al chromites within olivine grains in serpentinites and boninitic-like geochemistry in some of the meta-volcanic rocks indicate formation in a fore-arc setting. These may be correlated to the Mont-Orford or Lac-Brompton ophiolites in Québec. Early Ordovician? suprasubduction zone volcanic remnants are found throughout the Moretown and Cram Hill formations in Vermont. These include dikes of the Mount Norris Igneous Suite, the extent of which has recently been expanded, and flows of the Coburn Hill volcanics. Their chemistry, particularly distinct negative Nb anomalies, indicates they were formed in a marginal basin near a volcanic arc. These may be correlatives of the Bolton volcanics in Québec. The four volcanic groups can be explained as remnants of: 1) two stages of continental rift magmatism leading up to formation of Iapetus, 2) fore-arc ophiolites formed above an east-facing subduction zone that also formed the Shelburne Falls arc, and 3) magmatism associated with lithospheric delamination associated with collision of Laurentia with the Shelburne Falls arc or magmatism in a back-arc basin behind the Ascot arc.

II. GEOLOGIC SETTING

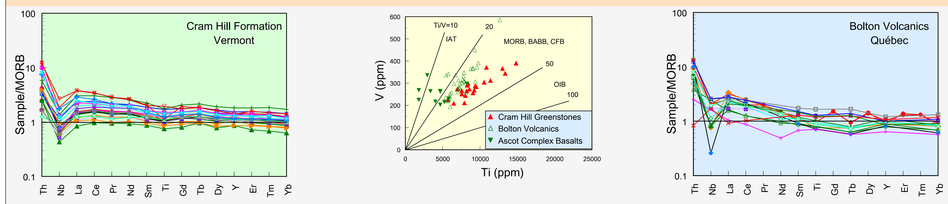


Geology of North Troy Quadrangle (Stanley & Roy, 1997; Ratcliffe, et al., 2011)

Geology of Montpelier Quadrangle (Ratcliffe, et al., 2011; Kim et al., 2003; Walsh et al., 2010)

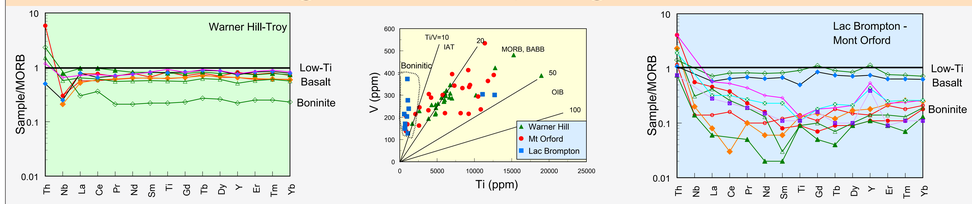
III. GEOCHEMISTRY

4a Cram Hill and Bolton Metavolcanics 4b



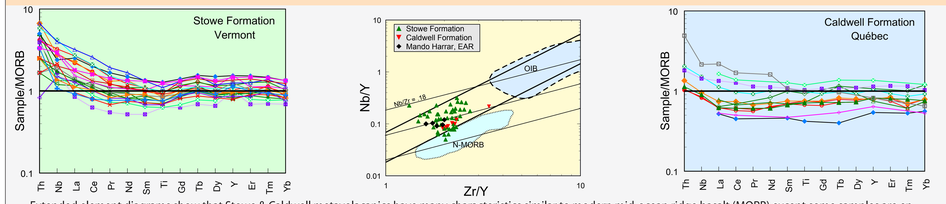
The distinctive negative Nb-anomaly of samples from this group suggest they formed in the vicinity of a volcanic arc. A marginal (back-arc) basin setting is preferred because the Nb anomaly is moderate, the basalts show a range of Ti contents typical of MORB and back-arc basin basalts (BABB), and there is a notable lack of felsic metavolcanics.. Note that basaltic compositions from the ~460 Ma Ascot arc show lower Ti, typical of arc volcanics. Data sources: Bolton Volcanics (Melancon et al., 1997); Ascot Complex (Tremblay et al., 1989).

3a Warner Hill, VT & Quebec Ophiolites 3b



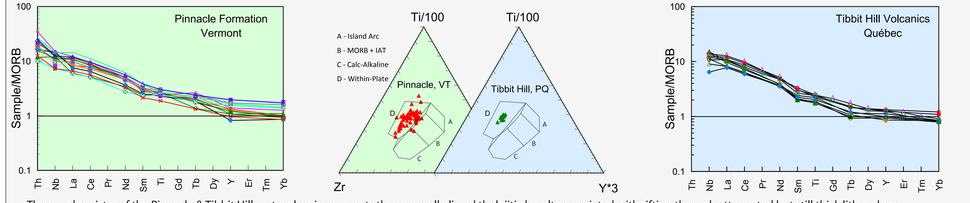
Low Ti, and U-shaped rare earth element patterns are characteristic of boninitic rocks; negative Nb anomalies in other samples suggest formation in the vicinity of a volcanic arc. The occurrence of boninitic and low-Ti arc-like samples suggest formation in a fore-arc region. Data on chromite from ultramafics in Vermont are also consistent with formation in a fore-arc region (Coish, 2010). Data from Québec ophiolites are from Huot et al. (2002) and De Souza et al. (2008). Fields in the Ti-Zr diagram are from Shervais (1982).

2a Stowe & Caldwell Metavolcanics 2b



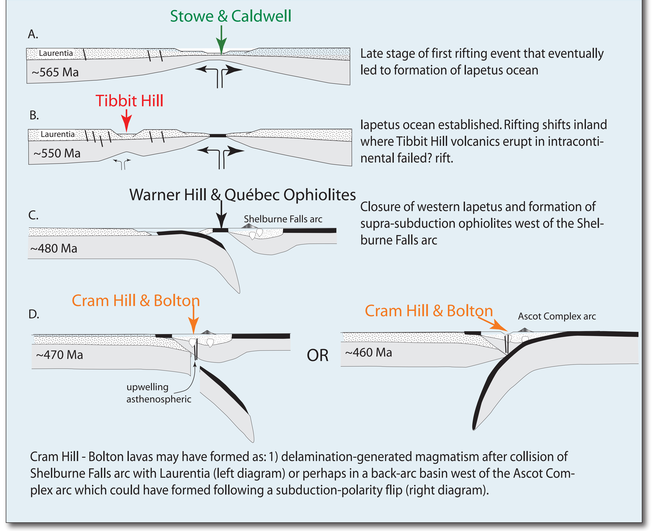
Extended element diagrams show that Stowe & Caldwell metavolcanics have many characteristics similar to modern mid-ocean ridge basalt (MORB) except some samples are enriched in some large ionic lithophile elements. Most samples are enriched in Nb/Y relative to MORB and are similar to some tholeiitic basalts from the East African Rift (EAR). This suggests that these metavolcanics formed during the end stages of rifting to form Iapetus rather than as true mid-ocean ridge basalts. Caldwell data from Bédard and Stevenson (1999); fields on Or/Y and Nb are from Fitton (2007).

1a Pinnacle and Tibbit Hill Metavolcanics 1b



The geochemistry of the Pinnacle & Tibbit Hill metavolcanics suggests they were alkali and tholeiitic basalts associated with rifting through attenuated but still thick lithosphere. Age of 554 Ma (Kumarapeli, 1989) is consistent with formation during second stage rifting of Iapetus (Cawood et al., 2001; Allen et al., 2010; Coish, 2010). Data for Tibbit Hill in Quebec are from Abdel-Rahman and Kumarapeli (1999).

IV. TECTONIC MODEL



Cram Hill - Bolton lavas may have formed as: 1) delamination-generated magmatism after collision of Shelburne Falls arc with Laurentia (left diagram) or perhaps in a back-arc basin west of the Ascot Complex arc which could have formed following a subduction-polarity flip (right diagram).

V. CONCLUSIONS

Remnants of Cambrian to Ordovician magmatic rocks can be directly traced across the Vermont- Quebec border in only two places: the Tibbit Hill volcanics and the Bolton volcanics (see map). Other correlations are made based on stratigraphic position and geochemical characteristics of mafic rocks.

Mafic rocks on both sides of the border trace the opening of Iapetus ocean in two stages at ~565 Ma (Stowe-Caldwell) and ~550 Ma (Pinnacle-Tibbit Hill). Initial stages of closing of Iapetus is preserved as ophiolite remnants (Warner Hill Complex and Québec ophiolites), formed in the fore-arc region of an east-dipping subduction zone. Marginal basin mafic rocks of the Cram Hill and Bolton Volcanics units may have formed as either delamination magmas following Shelburne Falls arc-continent collision or as back-arc magmas behind a new west-facing arc established following collision of the Shelburne Falls arc with the Laurentian continent.

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